(B)

# THE QUANTUM VIEW OF THE WORLD

(RETITLED NONLOCALITY, COUNTERFACTUALS AND THE QUANTUM THEORY

— St. ANDREWS, APRIL 1981)

(RETITLED CAUSALITY, RELATIVITY AND THE EPR PARADOX

— KEELE, SEPTEMBER 1981)

— AMSTERDAM, APRIL 1982.

— BOSTON, OCTOBER 1982

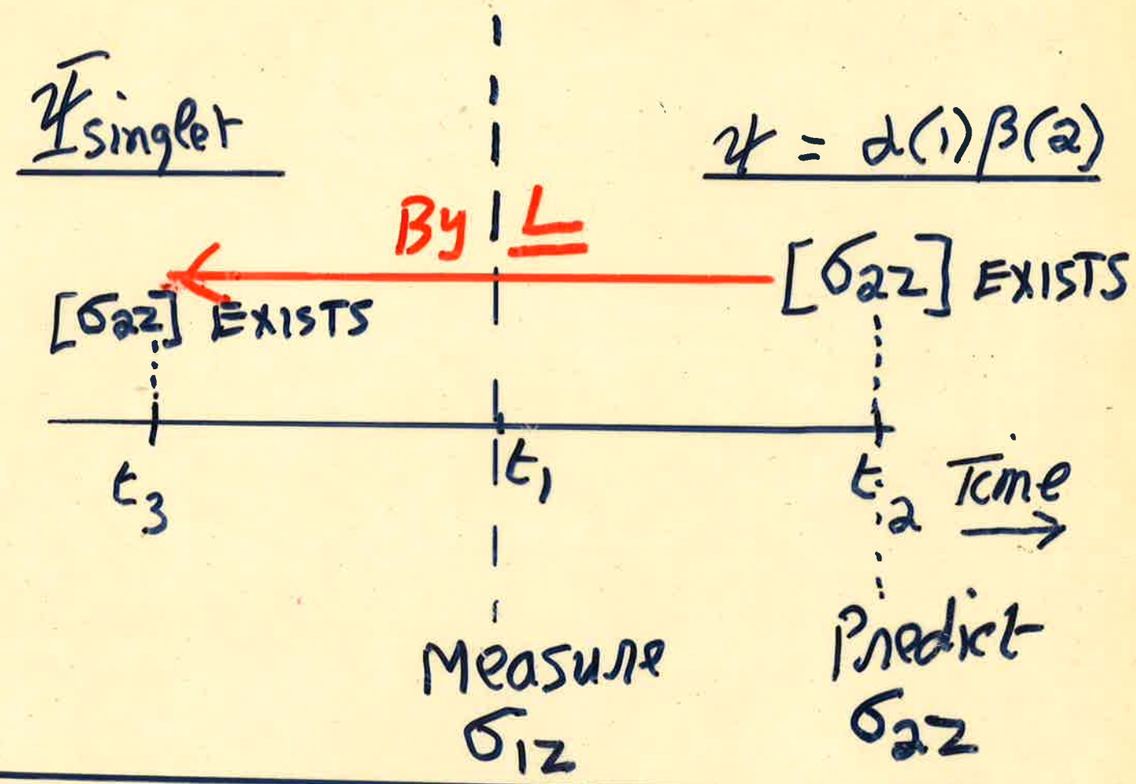
# SINGLET SPIN STATE FOR TWO SPIN-$\frac{1}{2}$ PARTICLES

$$\Psi_{\text{Singlet}} = \frac{1}{\sqrt{2}} \left( \alpha(1) \cdot \beta(2) - \beta(1) \cdot \alpha(2) \right)$$

$\alpha$ is state with Z-Component of spin $+\frac{1}{2}\hbar$

$\beta$ is state with Z-Component of spin $-\frac{1}{2}\hbar$

# THE EPR ARGUMENT




So QM ∩ LOC ⇒ Incompleteness

or QM ⇒ (¬LOC) ∨ Incompleteness

# LOCALITY IN THE EPR ARGUMENT

**Locality$_1$**: An unsharp value cannot be turned into a sharp value 'at a distance'.?

<u>or</u> should we really be talking about

**Locality$_2$**: An undefined value cannot be defined by measurements performed at a distance ?

# THE EPR ARGUMENT (1935)

QM + Locality$_1$ → Incompleteness

So

QM → non-locality$_1$

<u>or</u> Incompleteness

<u>But</u> Completion → non-locality$_3$ <u>(BELL)</u>

<u>So</u> both horns of the Einstein dilemma lead to some form of non-locality.

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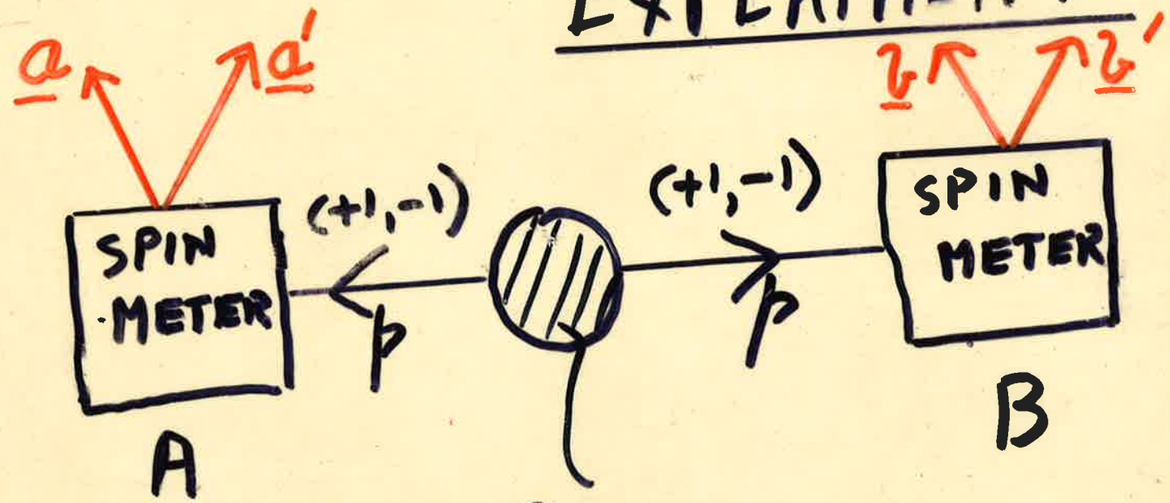
Locality$_3$: A sharp value cannot be changed into another sharp value 'at a distance'.

# THE BELL ARGUMENT

Locality$_3$ $\longrightarrow$ Bell Inequality

which is Contradicted
by QM (and
by experiment)

# THE BELL EXPERIMENT




$a_n$ denotes spin-component of A-particle parallel to direction $\underline{a}$ for $n^{th}$ pair of particles.
Similarly $a_n'$, $b_n$, $b_n'$.

# THE BELL INEQUALITY

Define Correlation Coefficients

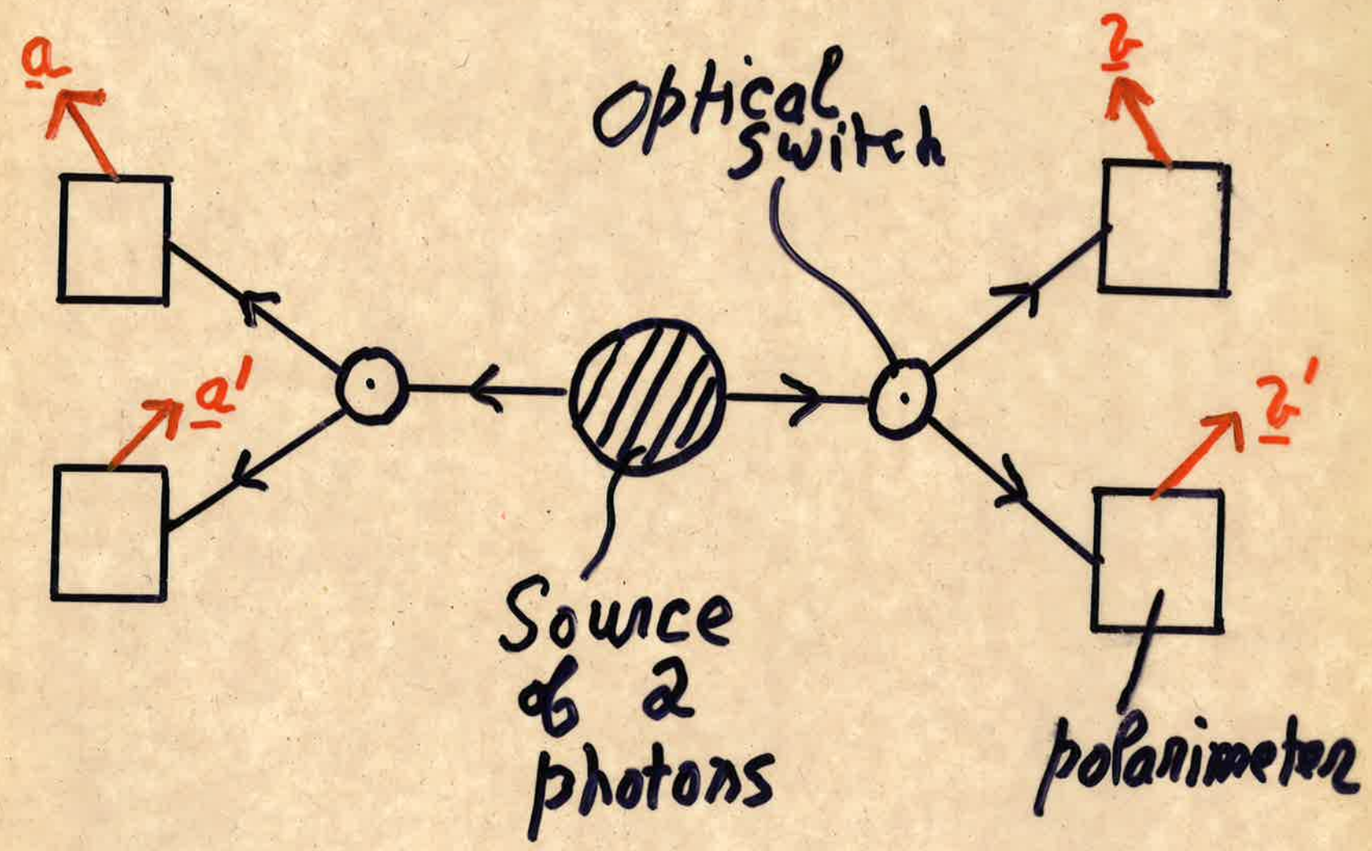
$$C(a,b) = \lim_{N\to\infty} \frac{1}{N} \sum_{n=1}^{N} a_n b_n$$

etc

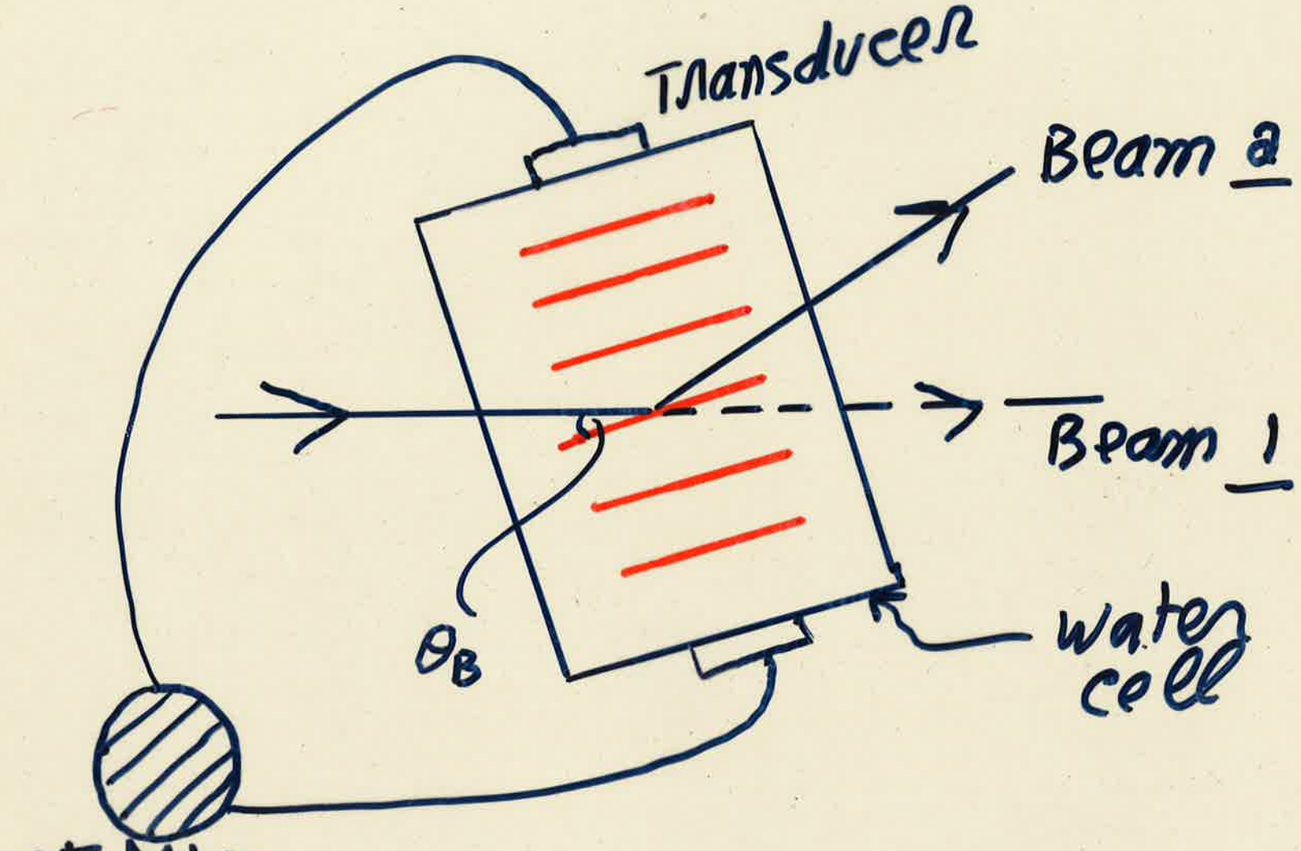
Then

$$| C(a,b) + C(a,b') + C(a',b) - C(a',b') | \leq 2$$

# ASPECT'S EXPERIMENT



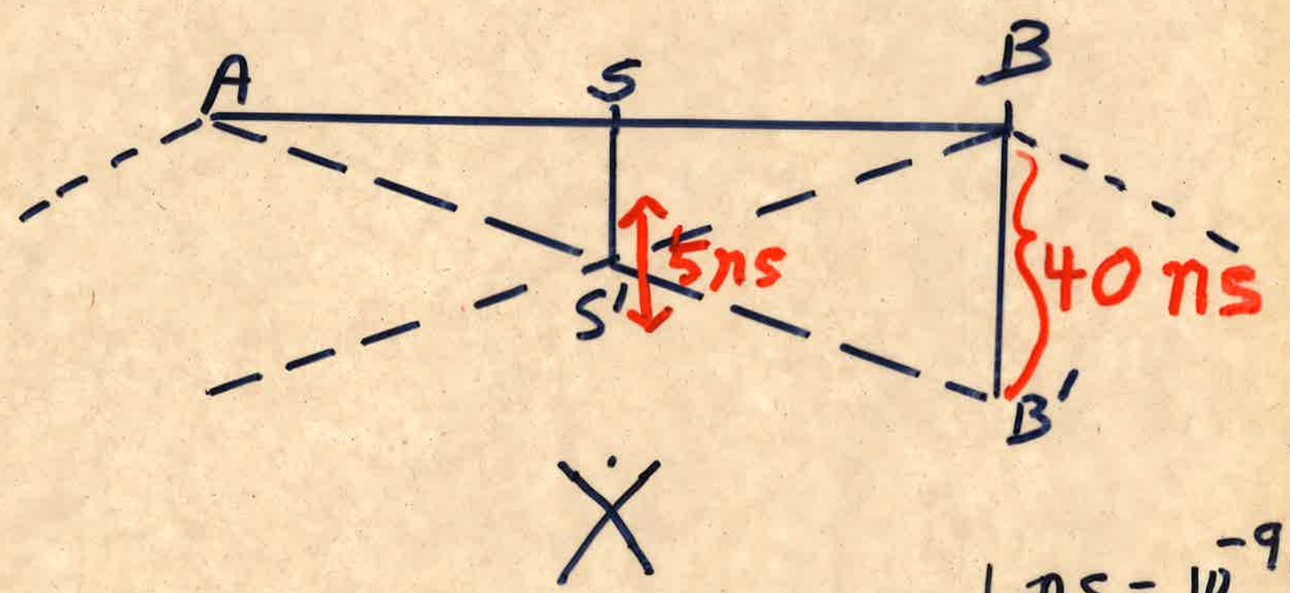
# THE OPTICAL SWITCH




$\theta_B$ = BRAGG ANGLE

$2\theta_B$ = DEFLECTION OF BEAM 2

# THE LIGHT-CONE STRUCTURE OF ASPECT'S EXPERIMENT




$1\ ns = 10^{-9}\ sec.$

# THE STAPP-EBERHARD APPROACH

Locality$_4$: A Macroscopic object cannot have its classical state changed 'at a distance'.

## THE PRINCIPLE OF LOCAL COUNTERFACTUAL DEFINITENESS (PLCD)

The result of an experiment which could be performed but is not has a definite value which does not depend on the setting of a remote piece of apparatus

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But in an intrinsically indeterministic situation the PLCD is suspect

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Example

| Location A | Location B |
| --- | --- |
| Actual Expt ↑ | Atom of Radium decays |
| Counter-factual Expt → | Would atom still decay? |

## LOCALITY 5

Consider the case where $\underline{a}$ and $\underline{b}$ are parallel, so we get perfect anticorrelation, Measuring $b_n \rightarrow a_n$ has value $-b_n$.

Now consider the sequence of results recorded at A

$$+ \; - \; - \; + \; + \; - \; + \; \ldots\ldots$$

Can we alter this sequence 'instantaneously' from location B?

# IS LOCALITY VIOLATED IN EPR?

| VIOLATES / VIEW | $Loc_1$ | $Loc_2$ | $Loc_3$ | $Loc_4$ | $Loc_5$ |
|---|---|---|---|---|---|
| A | no | no | yes | yes | no |
| B | yes | no | no | no | no |
| C | no | yes | no | no | no |

So If we want to preserve realism in QM we must give up locality$_1$ or locality$_3$.

Query: Would this conflict with Special Relativity?